INVESTIGATIONS ON PERIODICITY IN THE WEATHER

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INVESTIGATIONS on periodicity in the weather have occupied the attention of many workers, and I can refer only in a brief way to investigations along other lines than those on which I have been engaged.

A knowledge of the existence of annual and diurnal periods in the weather is older than history, and the fact that these periods depend on changes in the position of the sun is universally recognized. A large part of the labor of meteorologists at the present time is devoted to determining, for different parts of the world, the amount of change in weather conditions resulting from these periods.

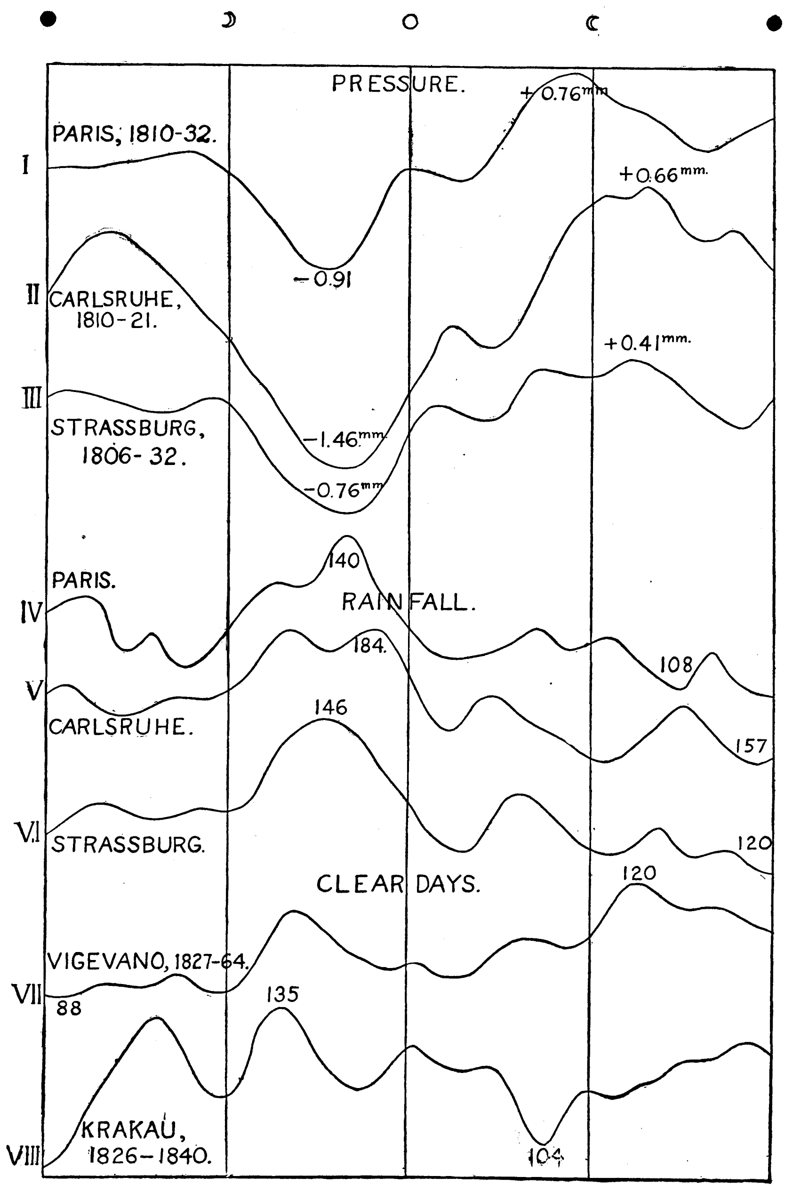
Many investigators have sought to prove a period in terrestrial magnetism and in meteorological phenomena coinciding with the rotation of the sun on its axis. Among these are Broun (Comtes Rendus, 1873), Hornstein (Sitzungsberichte Wien-Ak., 1873), Liznar (Sitzungsberichte Wien-Ak., 1885, '86, '87, and '88), Balfour Stewart (Nature, 1879 and 1884), Nerwander, (Poggendorffs Annalen, Bd. LVIII.), Buys Ballot (Archives Neerlandaises, Tom. XX.), Muller (Mélanges physiques et chemiques, Bull. Ac. St. Pét., 1886), Schmidt (Sitzungsberichte Wien-Ak., 1888), Veeder (Proc. Rochester Acad. Sci., 1889), Hall (Amer. Jour. of Sci., Vol. XLV., 1893), and Bigelow (Amer. Meteor. Jour., 1893). The results of these researches differ from one another, and none has received general acceptance.

Also there has been much study of the relation between the frequency of sun spots and corresponding periods in the weather. The results are conflicting, and the relation is not accepted as proved. The relation if it exists is undoubtedly complex, but this is what might be expected in meteorological phenomena. An excess of rainfall in India implies an increased ascent of air. This demands an increased descent of air in some other part of the world, as for example in Russia. Hence, an excess of rainfall in India would be coincident with a deficiency in Russia, and the two would have opposite phases in regard to the sunspot period,

as is found to be the case. Again, if during sunspot maxima there should be an increase in atmospheric pressure over the Mid-Atlantic, there would be an excess of southwest winds over the British Isles during this time. Since winds in blowing over mountain chains have their moisture condensed, and descend on the other side dry, the above conditions might result during a sunspot maximum in an excess of moisture on one side of a mountain chain and a deficiency on another. Hence, in an area as small as Scotland, opposite weather conditions in different places during the sunspot cycle do not necessarily disprove the existence of the cycle. The results of various investigators from various parts of the world need to be gathered and carefully considered from numerous standpoints, before the weather cycle can be said to be disproved, or before all the phenomena can obtain rational explanation as a result of the cycle.

Next to the sun, the heavenly body which has obtained most attention as a probable cause of weather cycles has been the moon. A popular belief in the influence of the moon on the weather is older than history, and exists in full vigor to-day. The earlier meteorologists, attracted by this general belief, devoted much time to investigating the question of the relation of weather to the moon's position. Considerable data of various kinds were accumulated, to which full references are found in Van Bebber's Handbuch der Witterungskunde. The results given in most detail were plotted by Van Bebber, and are here reproduced in Plate I. from traces made with a pantograph. Curve I. was plotted from the mean atmospheric pressure at Paris for each day of the synodic period of the moon, as obtained by Eugene Bouvard for the twenty-three years 1810–32. Curves II. and III. are the means of the atmospheric pressure at Carlsruhe and Strassburg for each day of the synodic period of the moon, as obtained by O. Eisenlohr for the years 1810–21 and 1806–32, respectively. The three curves are in close agreement, showing a minimum pressure about midway between the first quarter and full moon and a maximum near the last quarter. Curves IV., V., and VI. show the number of rainy days at Paris, Carlsruhe, and Strassburg for each day of the synodic period as worked out by Bouvard and Eisenlohr for the intervals given above. These curves are alike, and show a maximum frequency of rainy days at the time of the minimum of pressure. Curves VII. and VIII. show the number of clear days at Vigevano and Krakau for each day of the synodic period as obtained for the first place by Schiaparelli for the interval 1827–64 and for the second place by Wierzbicki for the interval 1826–40. The curve for Vigevano shows the

PLATE I.


PRESSURE.
I
PARIS, 1810-32.
+0.76mm
−0.91
II
CARLSRUHE, 1810-21.
+0.66mm.
III
STRASSBURG, 1806-32.
+0.41mm.
−1.46mm
−0.76mm
RAINFALL.
IV
PARIS.
140
108
V
CARLSRUHE.
184.
157
VI
STRASSBURG.
146
120
CLEAR DAYS.
VII
VIGEVANO, 1827-64.
88
120
VIII
KRAKAU, 1826-1840.
135
104

maximum frequency of clear days about the time of the last quarter of the moon, corresponding with the time of maximum pressure at Paris, Carlsruhe, and Strassburg. The curve for Krakau, however, shows the opposite condition. For purposes of comparison Van Bebber collected in tables the results of various investigators. The results showing the relation of the moon's phases to atmospheric pressure are given in Table I., except that two stations where the interval of observation did not exceed five years are omitted. In a large proportion of these results the minimum of barometric pressure is about the time of the moon's second octant and a maximum about the time of the last quarter. The range from maximum to minimum is small, but the stations cover a considerable portion of Europe and there is one as distant as Batavia. The general agreement of the results is surprising in view of the fact that some of the investigators were seeking to disprove the lunar period in atmospheric phenomena, or at any rate were sceptical of its existence. It is improbable that the pressure is high over all the earth at the same time, so that future investigators will probably find opposite phases of the period for different parts of the world.

In Plate II. are curves plotted from the mean temperature for each day of the lunar synodic period. They are drawn by means of a pantograph from curves given by J. Park Harrison in the Proceedings of the Royal Society of May 4, 1865, except No. IV., which I derived from thirteen years' observations at the Blue Hill Meteorological Observatory (1886–98). The curves were plotted from the unsmoothed mean of each day of the period. No. I. is from the daily mean of temperature at Greenwich, Eng., from 1856–64. No. II. is from the minimum temperatures for the same interval at the same place. No. III. is from the daily means of temperature at Oxford, Eng., from 1859–61. No. IV. is from the daily means of temperature at Blue Hill, Mass., from 1886–98. No. V. is from the daily means of temperature at Oust Silosk, Siberia, from 1837–43. The maximum and minimum values are given by numerals printed near the curves. The curves are irregular and the ranges not large, but they all agree in showing a generally higher temperature between new moon and full than between full moon and new. At the European stations the warmest weather seems to be about the first quarter, and the coldest about the last, thus agreeing approximately, either directly or inversely, with the times of maximum found by other investigators for the pressure and for the number of rainy days.

In Plate III. are curves showing the number of thunderstorms on each day of the moon's synodic period. No. I. is plotted from results

TABLE I.

RELATION OF THE MOON'S PHASES TO THE AIR-PRESSURE. (DEPARTURE FROM THE MEAN.)

Author.	Station.	New Moon.	1st Octant.	First Quarter.	2d Octant.	Full Moon.	3d Octant.	Last Quarter.	4th Octant.
		mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Hallaschka . . .	Prag, 1818/27	+0.68	−0.20	+0.34	−1.04	+0.29	−0.88	+0.07	−0.16
Flaggergues . . .	Viviers, 1808/27	−0.05	−0.07	−0.07	−0.72	−0.21	+0.26	+0.88	+0.04
Bouvard	Paris, 1810/32	+0.06	−0.21	+0.11	−0.74	−0.21	−0.09	+0.76	+0.49
Eisenlohr . . .	Paris, 1819/40	+0.14	−0.24	−0.11	−0.11	+0.06	−0.08	+0.30	+0.03
"	Carlsruhe, 1810/21	+0.16	+0.69	−0.09	−1.38	−0.75	−0.55	+0.91	+0.78
"	Strassburg, 1806/32	+0.27	−0.02	−0.05	−0.82	+0.39	+0.22	+0.44	−0.02
Mädler	Berlin, 1820/35	+1.10	. . .	+0.67	. . .	−0.09	. . .	−0.02	. . .
Lüdicke	Gotha, 1867/75	+0.39	. . .	−0.50	. . .	−0.57	. . .	+0.68	. . .
Streintz	Greenwich, 1848/67	−0.40	−0.02	+0.46	+0.03	−0.39	−0.51	+0.03	+0.76
Bergsma	Batavia, 1866/80	−0.11	+0.00	−0.01	−0.00	+0.03	+0.04	+0.09	−0.03

PLATE II.

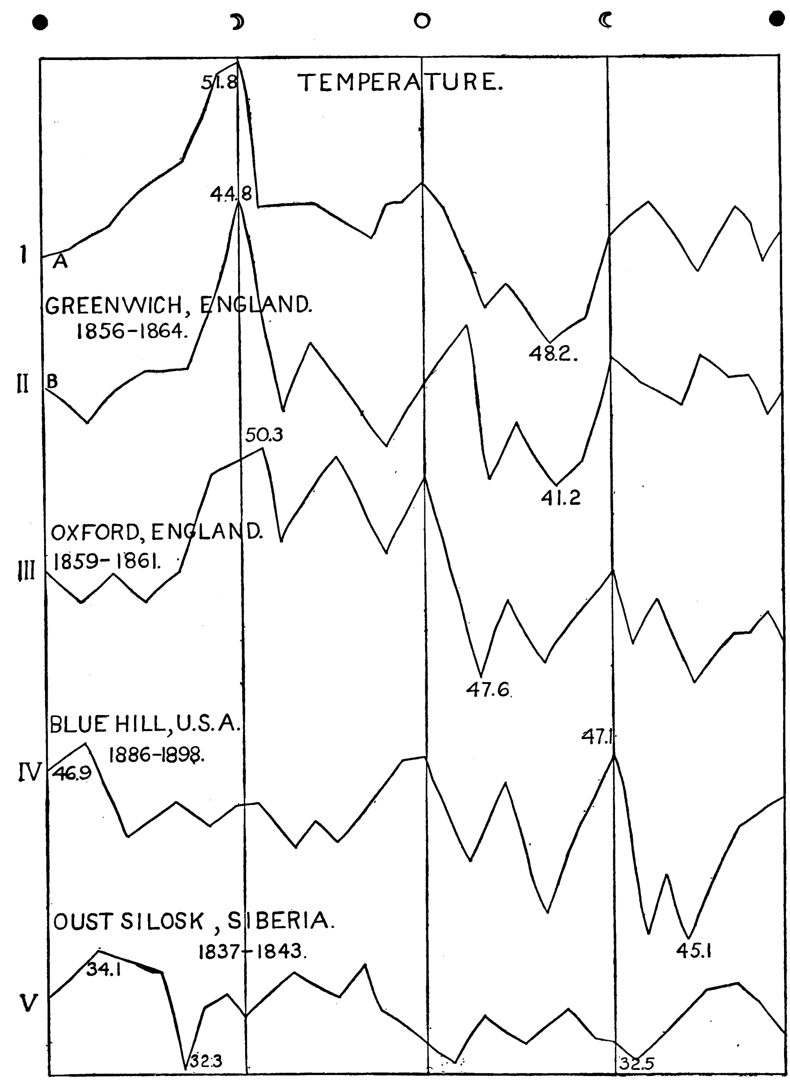
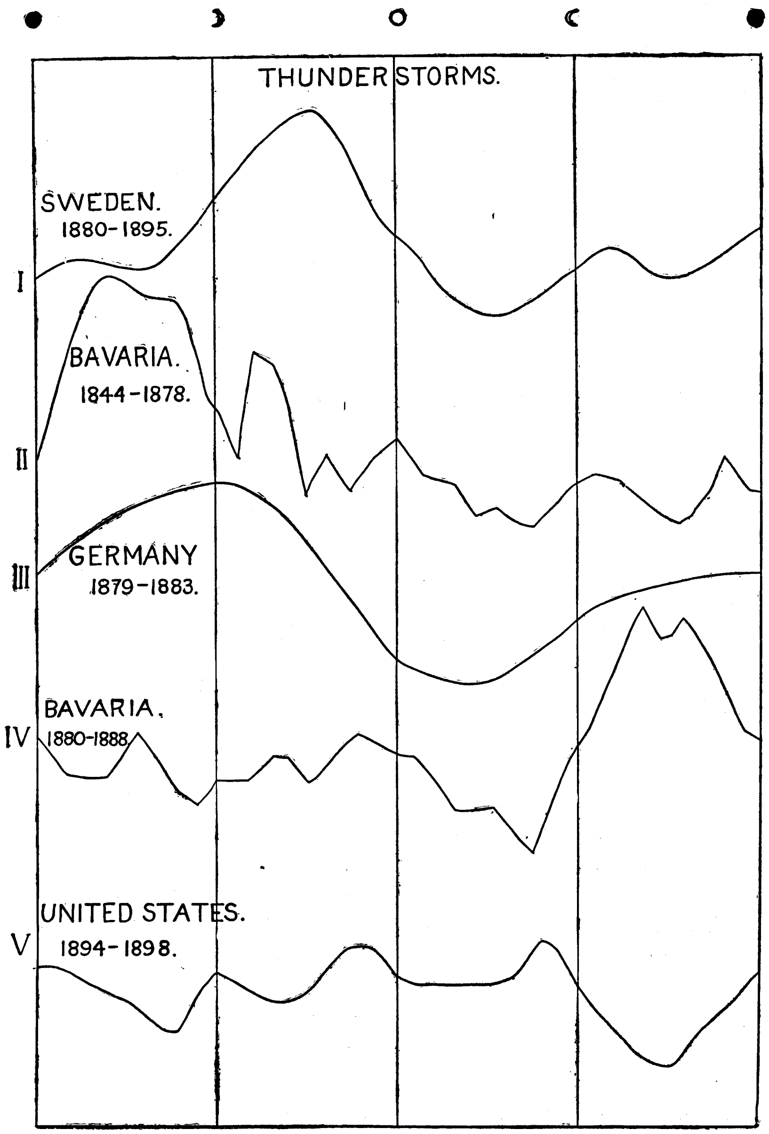

TEMPERATURE.
51.8
44.8
48.2.
50.3
41.2
47.6.
47.1
45.1
34.1
32.3
32.5
46.9
I
A
GREENWICH, ENGLAND.
1856-1864.
II
B
OXFORD, ENGLAND.
1859-1861.
III
BLUE HILL, U.S.A.
1886-1898.
IV
OUST SILOSK, SIBERIA.
1837-1843.
V

PLATE III.


THUNDER STORMS.
SWEDEN.
1880-1895.
I
BAVARIA.
1844-1878.
II
GERMANY
1879-1883.
III
BAVARIA.
1880-1888.
IV
UNITED STATES.
1894-1898.
V

obtained by Dr. Ekholm and Mr. Arrhenius from the thunderstorms observed throughout Sweden in 1880–95. The unsmoothed results give a decided maximum of thunderstorms (50 per cent above the mean) on the third day after the first quarter, and a minimum (34 per cent below the mean) three days before the last quarter. But the plotted curve is irregular and the curve given here is plotted from the results smoothed by a process described in the pamphlet "Ueber den Einfluss des Mondes auf die Polarlichter und Gewitter, von Nils Ekholm und Svante Arrhenius" (Swedish Academy of Science, 1898). No. II. shows the number of lightning strokes which were recorded in Bavaria from 1844–78 as determined by E. Wagner for each day of the moon's synodic period (Meteorologische Zeitschrift, August, 1889). No. III. is from the number of thunderstorms found in Germany by Dr. Koeppen for each quarter of the moon from 1879–83 (Meteorologische Zeitschrift, January, 1885), A smooth curve is plotted through the numbers at each quarter. No. IV. is plotted from the number of thunderstorms in Bavaria found by E. Wagner for each day of the synodic period from 1880–88. Before plotting, the numbers were smoothed by taking the mean of each five. No. V. was plotted from the total number of thunderstorms on each day of the period from 1894–98, determined for me by Mr. A. E. Sweetland. The results were reduced to percentages, and smoothed by getting the second mean of each successive two before plotting. The range is from +8 to —12 per cent of the mean.

The well known meteorologist Luke Howard was much interested in the question as to whether there was a period in the weather corresponding to the tropical period of the moon, or to the time of its movement back and forth across the plane of the earth's equator. From a careful study of the observations made in the vicinity of London, for the eighteen years from 1815–32, he arrived at the conclusion that the most rain (by measure at the earth's surface) falls in the weeks when the moon is south of the equator and least when it is passing over the equator southward, the full north declination and the week during which it is approaching the equator having a mean quantity. "On investigating the connection of rain with thunder he finds that the atmosphere of our climate is sensibly more subject to electrical accumulation in the clouds and to the consequent changes when the moon is either south of the equator or returning from that position." From his studies of the air temperature he deduces the following conclusions: "(1) That the pressure of an atmospheric tide which attends the approach of the moon to these latitudes, raises the mean temperature 0.35 of a degree. (2) That the

rarefaction under the moon in north declination lowers the temperature 0.13 of a degree. (3) That the northerly swell following the moon as she recedes to the south further cools the air 0.18 of a degree. (4) That this cold continues while the moon is away south, reducing the mean temperature yet lower by 0.04 of a degree." (Papers on Meteorology, etc., by Luke Howard, F. R. S., London, 1854, p. 44.) In showing the greatest number of thunderstorms when the moon is south, Howard's results agree with the later ones of Dr. Ekholm and Arrhenius and of Mr. Sweetland and myself. M. P. Garrigou Lagrange of the Observatoire Physique et Météorologique, at Limoges, France, investigated the relation between the moon's change in declination and the change in the pressure of the atmosphere over the northern hemisphere, using for this purpose the international observations of 1882–83. His conclusions as communicated to the Société Météorologique de France are: — (1) In the atmosphere of the northern hemisphere there exists an oscillation from one side to the other of about the 30th parallel synchronous with the movement of the moon in declination and of such a nature that when the moon is north the pressure is lower below the 30th parallel and higher above it, and inversely when the moon is south. (2) The gradients show correlative modifications. The barometric slope from latitude 30° toward the south and toward the north is alternately raised and lowered, being steepest below 30° when the moon is north and less steep above 30° and inversely when the moon is south. (3) These differences in the pressure and the gradients increase in proportion as one advances toward the pole, at least as far as the 70th parallel. (4) These movements are superposed on the more general movements which they strengthen or weaken as they are in the same or in a contrary direction.

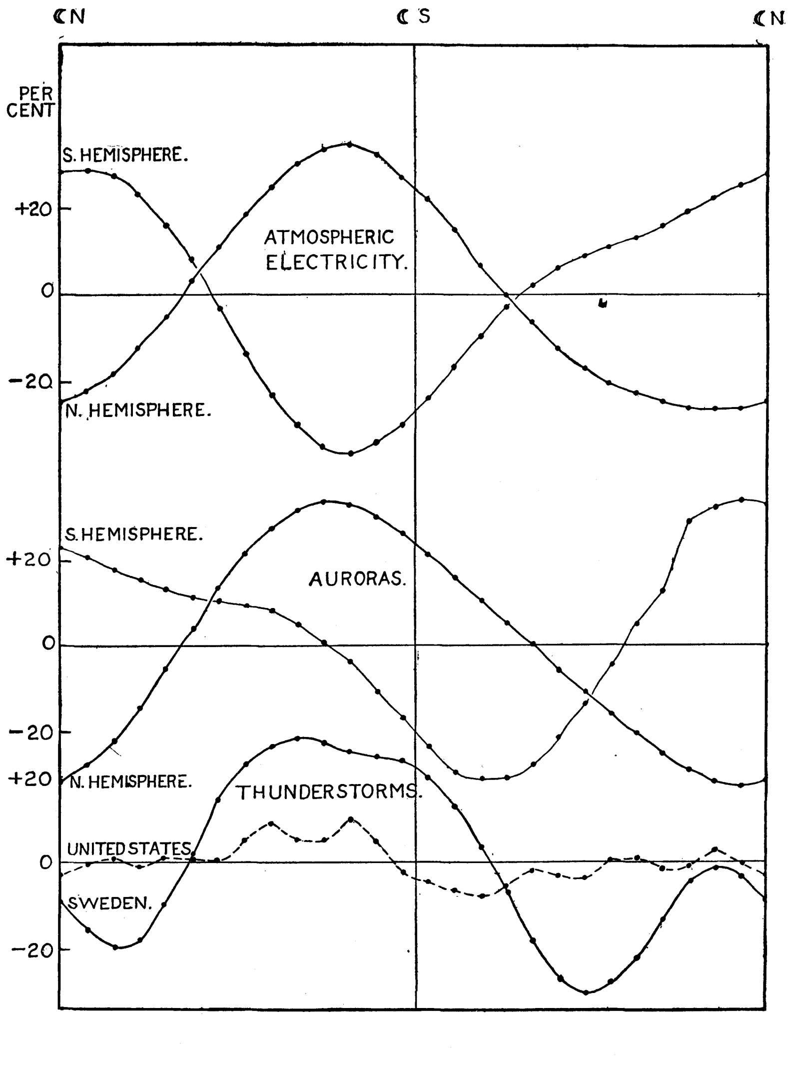
In 1894, Dr. Nils Ekholm and Svante Arrhenius published an investigation on the relation between the electrical potential of the air and the position of the moon in declination. (Ueber den Einfluss des Mondes auf den Electrischen Zustand der Erde, Bihang till K. Svenska Vet. Akad. Handlingar, Band XIX., Afd. I., No. 8, Stockholm, 1894.) They found that in the northern hemisphere the difference in potential between the earth and air was greatest when the moon was in southern declination while in the southern hemisphere it was greatest when the moon was in northern declination, the variations being 20 per cent or more above and below the mean. In Plate IV. the curves marked "Atmospheric Electricity" show the results for Cape Horn and Cape Thordsen (Spitzbergen). The curve marked "S. Hemisphere" is for Cape Horn; the one marked "N. Hemisphere" is for Cape Thordsen. The explanation

suggested for this phenomenon was that the moon is negatively electrified like the earth, and, acting by induction on the earth's surface, diminishes the electrical potential on the portion of the earth nearest the moon and increases the potential on the opposite side of the earth. In 1896–97, from observations made throughout the United States, I investigated the relation of the frequency of auroras to the moon's position in declination, and found the greatest number of auroras when the moon was in south declination. (Paper read before the Boston Sci. Soc., May 11, 1897. See Boston Evening Herald of May 12, 1897, and Amer. Jour. of Science of February, 1898.)

In 1898, Dr. Ekholm and Mr. Arrhenius published an exhaustive and most careful research on the relation of auroral frequency to the position of the moon in declination, in which the various sources of error which might influence the results were considered and eliminated. (Ueber den Einfluss des Mondes auf die Polarlichter und Gewitter, von Nils Ekholm and Svante Arrhenius, Bihang der k. schwedischen Akad. d. Wissenschaften, 1898.) They made use of all the available observations both in the northern and southern hemispheres. Their results from all the observations in each hemisphere are plotted in the curves marked auroras in Plate IV. The curves are nearly opposite in phase, and clearly follow the same course as that of atmospheric electricity shown in the upper part of the same plate. Ekholm and Arrhenius also determined the frequency of thunderstorms in Sweden as related to the moon's position in declination, and their results are plotted and marked thunderstorms in Plate IV. The frequency follows the same course as that of the auroras and of the amount of atmospheric electricity except that there is a secondary maximum about the time of the moon's greatest northern declination, a phenomenon which I found also for auroras in the United States. From the observations in the United States published in the Monthly Weather Review, Mr. A. E. Sweetland worked out for me the frequency of thunderstorms as related to the moon's position in declination and obtained the results plotted in the broken curve marked United States. The range is very small but the curve follows a similar course to the one for Sweden showing a maximum a few days preceding the greatest northern declination.

My work in meteorology was instigated by the popular belief in the influence of the moon on the weather. The general prevalence of this belief led me when a youth to investigate whether the weather conditions supposed to follow certain positions of the moon really did so. I found the subject a complex one, and, taking up the study of modern mete-

PLATE IV.



☾N
☾S
☾N
PER CENT
S. HEMISPHERE.
+20
ATMOSPHERIC ELECTRICITY.
0
−20
N. HEMISPHERE.
S. HEMISPHERE.
+20
AURORAS.
0
−20
+20
N. HEMISPHERE.
THUNDERSTORMS.
UNITED STATES.
0
SWEDEN.
−20

orology, I adopted the general belief of meteorologists that, as there was no rational reason why the moon should influence the weather, it probably did not. I had, however, in my investigation found evidence of periodic changes in the weather independent of the annual and diurnal periods. I decided to lay aside any theory as to their cause, and to determine as definitely as possible the lengths, ranges, and methods of oscillation of the periodic changes. My investigations led me to the following conclusions which I believe are important: — (1) That every weather period is rendered complex by the existence of periods which bear the relation of harmonics to the primary, that is, their lengths are twice, one half, one third, one fourth, etc., the length of the primary. (2) The periods in different parts of the world have different phases, as for example in the annual period it is cold in the northern hemisphere when it is warm in the southern, and in the sunspot period it is dry in Russia when it is wet in India. (3) At any given place on the earth's surface the harmonics, and in some cases the primaries, reverse in phase. In the case of some of the longer periods this has been traced to a movement of the centre of oscillation from place to place. (4) At any given place the periods and their harmonics do not vary synchronously. Sometimes the primary period is weak, while one or more of the harmonics are strong, and the reverse.

One of my earliest investigations, made in 1882–84, was concerning a period of about two years which I now believe is a periodic change in the weather, arising from the annual period, and having twice its length. The results were published in the American Meteorological Journal for August, 1884, and April, 1885. Some of the diagrams are here reproduced. The continuous curve in Plate V. was obtained by taking the average of the monthly barometric means for each twelve consecutive months from 1874 to 1881. The dotted curve was obtained by taking the mean of each consecutive twenty-five months. The dotted and broken curves in Plate VI. were obtained in the same way for the rainfall. In each case the annual period is eliminated, and the unbroken curves show secondary oscillations in pressure and rainfall with about two years between each maximum and minimum.

That the same oscillation prevailed in the temperature is shown by Table II., page 613, giving the departures from the average temperature.

On the eastern coast of the United States the oscillations in pressure were found to be opposite in phase to those over the interior. A table was made showing the departures from the average of twenty-five months at the times of the maxima and minima of the waves. These

PLATE V

PRESSURE.

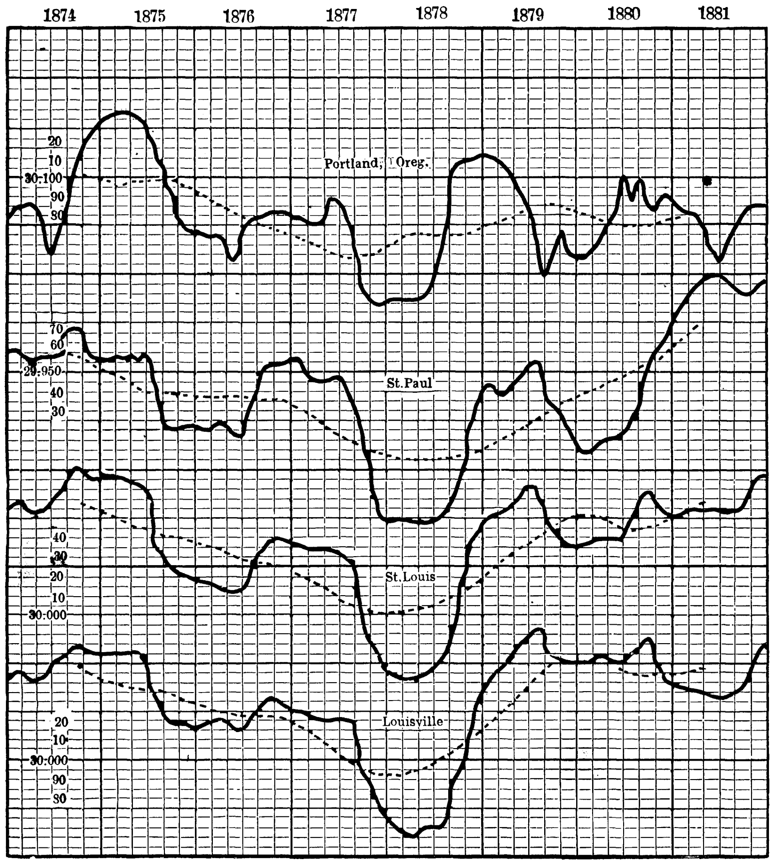


PLATE VI.

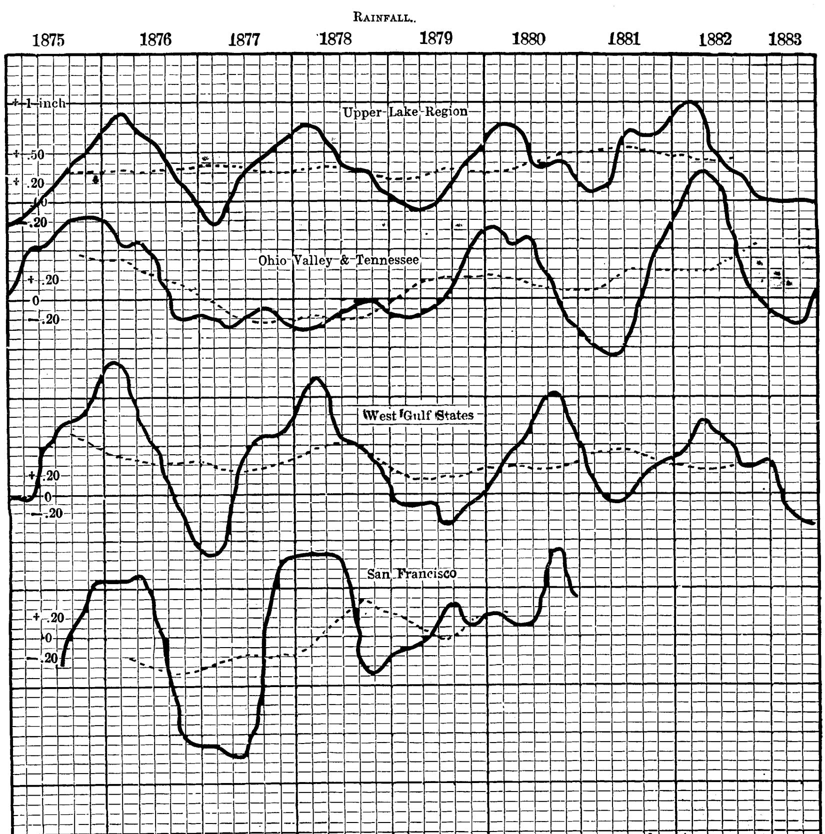

RAINFALL.
1875
1876
1877
1878
1879
1880
1881
1882
1883
+ 1 inch
+ .50
+ .20
0
– .20
Upper Lake Region
+ .20
0
– .20
Ohio Valley & Tennessee
West Gulf States
+ .20
0
– .20
San Francisco
+ .20
0
– .20

TABLE II.

DEPARTURES OF TEMPERATURE FROM NORMAL.

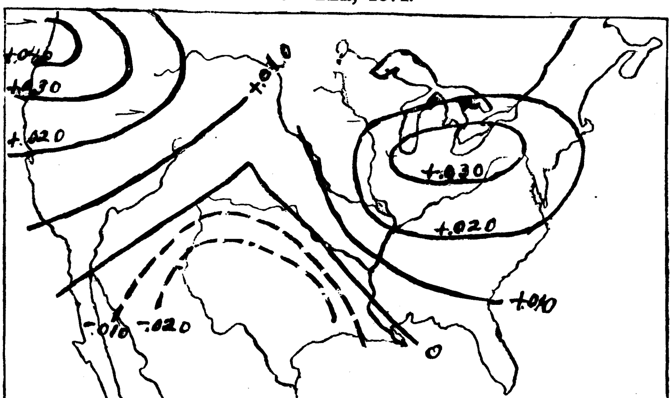
	Winters of					
	1874-5.	1875-6.	1876-7.	1877-8.	1878-9.	1879-80.
	° F.	° F.	° F.	° F.	° F.	° F.
Upper Lake Region . . .	–21.90	+12.40	–0.30	+32.00	–1.20	+13.90
Ohio Valley and Tennessee	–8.30	+22.10	–3.80	+17.20	–7.60	+25.10
West Gulf States	–1.30	+16.10	–7.90	+3.60	–7.00	+19.10
South Atlantic States . .	–0.10	+11.10	–9.00	+3.60	–4.00	+27.60

were charted on a map and lines of equal departure drawn. These lines are shown in Plates VII. and VIII. The continuous lines show plus departures and the broken lines show minus departures. The results show that there were distinct centres of oscillation which had a movement in space. From this it follows that the phase of the period at any one point on the earth's surface will reverse, and the range and form of the cycle cannot be found from averages of observations taken at one point during a great many periods.

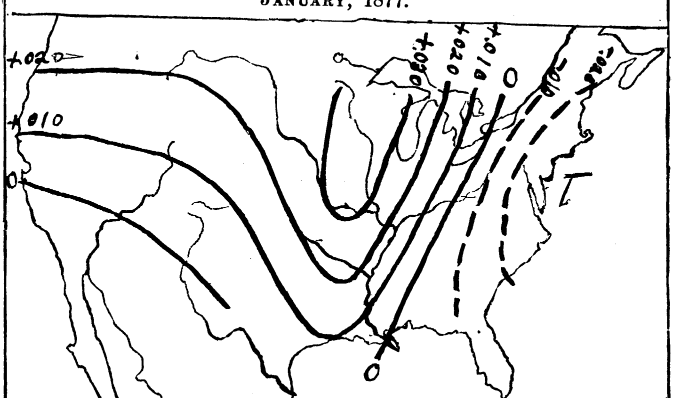
The next period which attracted my attention were oscillations in the temperature of about thirty and of about seven days. The results of these investigations were published in the American Meteorological Journal for June and August, 1895. The seven-day period was found to be about one fourth the length of the thirty-day period, and hence was assumed to be a harmonic of the latter. (American Journal of Science, March, 1894.) By grouping the phenomena into periods of three years, I found a certain constancy in the average position of the maxima and minima of the seven-day period, and ascertained the length of the period as 7 days 6.4 hours. In 1894, with the assistance of Mr. Sweetland, I ascertained the range of all the periods which were multiples of this length up to fifty-eight days. It was found that the period of about twenty-nine days gave the greatest range, and this led me to consider whether the synodic rotation of the moon was concerned in the matter. It was found that the length of my seven-day period would be of the same length as one quarter of the synodic rotation of the moon if the number of periods had been assumed one less in the three-year groups in which I had arranged the phenomena. It followed that the lunar period

PLATE VII.

December, 1874.



January, 1877.



February, 1879.

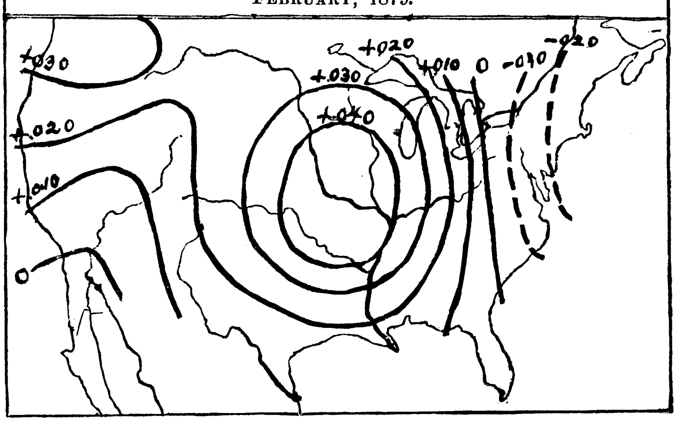
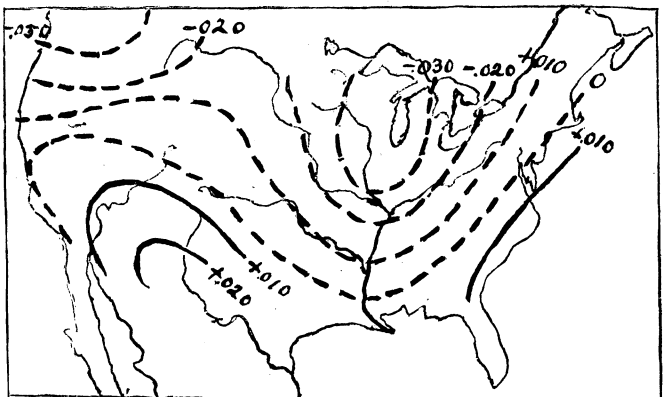
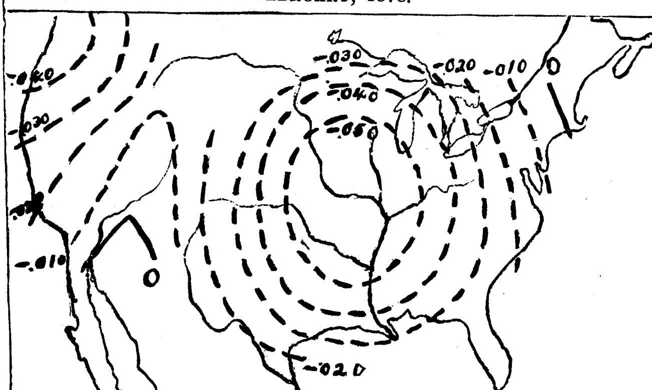


PLATE VIII.

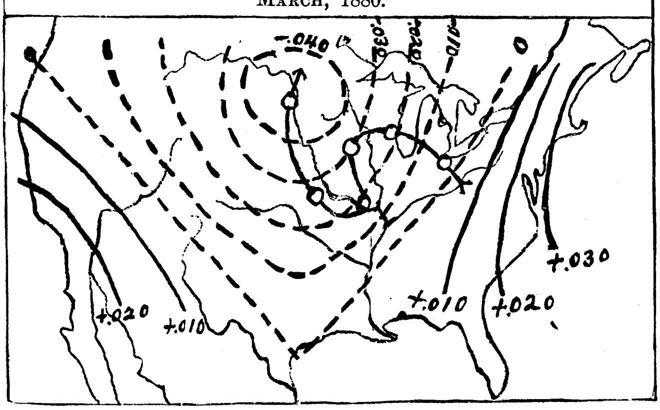
DECEMBER, 1875.



FEBRUARY, 1878.



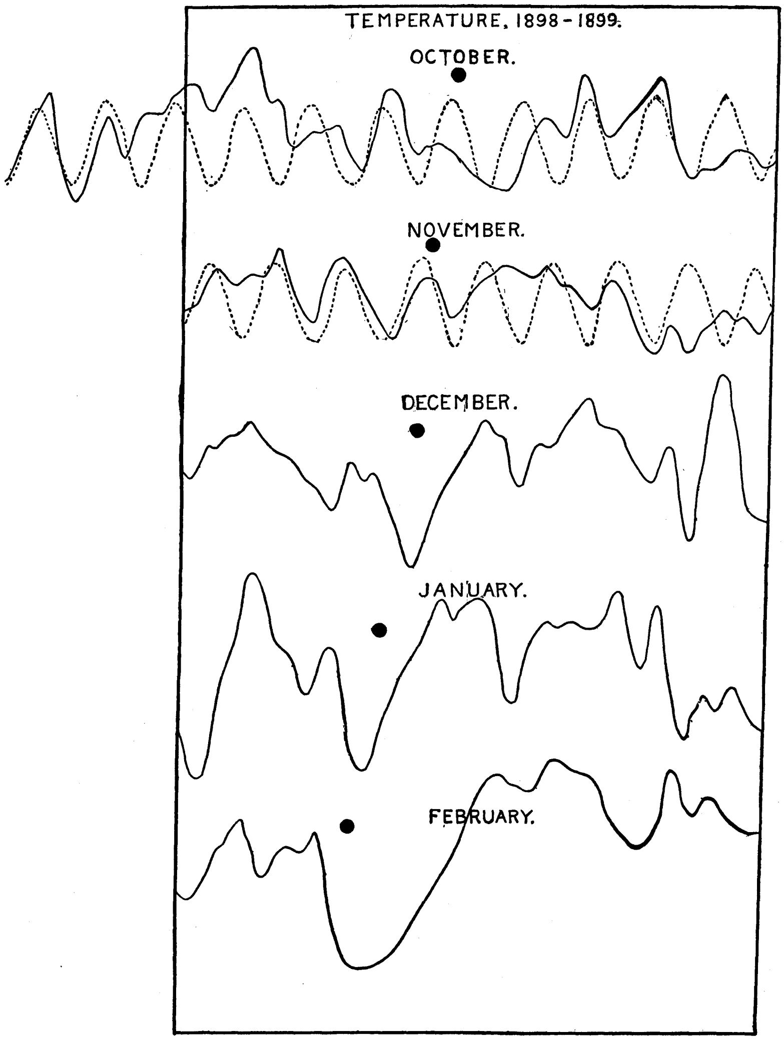
MARCH, 1880.



would fulfil the condition as well as the period I had supposed, and I was led to adopt the length of the lunar periods in my investigations as a working hypothesis. This seems justified by the fact that other investigators have found certain constant relations between the positions of the moon and weather phenomena as described in the foregoing pages. The average changes in the weather conditions as related to the moon appear to be very small, and meteorologists have heretofore assumed that, if such a relation existed, it was so small as to be negligible. However, since certain of the weather periods have been found to reverse in phase, is it not possible that periodic motions in the atmosphere set up in some way by the motions of the moon may be much larger than shown by the average for a long time at any given place?

On Plate IX. are plotted the mean daily departures from the normal temperatures at Blue Hill from October, 1898, to February, 1899. It is seen that during October and November there was a rise and fall in temperature about every three and a half days, which is about one eighth of a lunar period. A dotted curve representing a harmonic exactly one eighth of the synodic period of the moon is plotted for comparison with the observed temperatures. The curves show that for every maximum of the dotted curve there was a corresponding maximum of the observed temperature, though the two were not always synchronous, and near the end of November the phenomenon of reversal of phase appears. Furthermore, it is seen that the minimum temperatures of October, December, January, and February occurred very near the times indicated by the round black circles. These circles indicate the time of new moon, and show that the intervals between the minima approximate the length of a synodic period of the moon. Moreover these minima were from 10° to 30° F. below the normal of the time of year, and, if periodic, were the result of some strongly acting cause. Whatever the cause of these oscillations may be, a knowledge of the laws controlling their action would be of vast importance for weather forecasting. An urgent present need is to find the reason for, or the law of, their reversal of phase. Such researches deserve financial aid and sympathy. The problems to be solved are fascinating and important, and in the time which can be spared from other pursuits I am making an earnest effort to find a clue to the cause or the method of the reversals. One cause appears to be a movement of the centres of oscillation. In other cases there is evidence of an annual period. Taking, for example, Luke Howard's tables, which show for the eighteen years 1815–32 the mean temperatures for the weeks when the moon was in south and in north declination respectively, I found the

PLATE IX.


TEMPERATURE, 1898 - 1899.
OCTOBER.
NOVEMBER.
DECEMBER.
JANUARY.
FEBRUARY.

differences between them. An excess of temperature when the moon was south was indicated by a plus sign, and a deficiency by a minus sign. Dividing the year into thirteen lunations, averages of these differences were obtained for each lunation with the following results: —

	Jan.	Feb.	March.	April.	May.	May-June.	June-July.
1815–23	–4.1	+2.2	–2.6	–1.9	–3.8	–1.8	+0.4
1824–32	+2.4	–2.9	–0.4	–3.8	–2.5	–2.6	–3.6
1815–32	–0.8	–0.4	–1.5	–2.9	–3.2	–2.2	–1.1

	July-Aug.	Aug.	Sept.	Oct.	Nov.	Dec.
1815–23	–1.0	+0.8	+2.9	+0.3	+4.3	+4.3
1824–32	+1.8	+1.6	+1.1	+3.6	+0.7	–0.2
1815–32	+0.4	+1.2	+2 0	+2.0	+2.5	+2.0

These figures indicate that, when the sun is moving from south to north declination, January to June, the air averages colder when the moon is south than when north of the equator; on the other hand, when the sun is moving from north to south declination, July to December, the air averages warmer when the moon is south. The greatest average differences are about 3° F., and occur near the first of May and November respectively, about six weeks after the equinoxes. There are other periods in the reversals of phase, but to recount the numerous methods by which I have tried to isolate them and to determine their length would be tedious and unnecessary, as the results are as yet undeveloped.